

BELLCOMM, INC.

955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024

B70 05061

SUBJECT:  $\Delta$ RLS Updates During the Braking Phase  
of LM Descent Using Explicit and Delta  
Guidance - Case 310

DATE: May 25, 1970

FROM: P. A. Whitlock

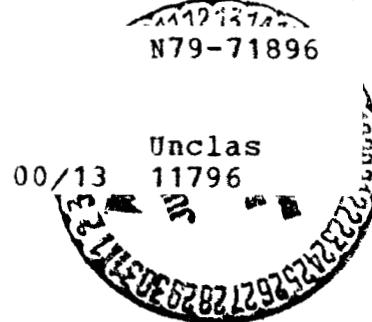
ABSTRACT

This memorandum presents a study of the  $\Delta V$  cost of updating the landing site ( $\Delta$ RLS) early in the braking phase of LM descent. A comparison is made between a trajectory using Apollo 12-13 targets and one using the delta guidance equations. In addition, the Apollo 12-13 data is compared with the results of a previous study made using Apollo 11 targets. The effects of errors in altitude at ignition and thrust variations are studied using each of the guidance schemes.

It was found that downrange  $\Delta$ RLS updates within 6 minutes after ignition using Apollo 12-13 explicit guidance cost about 9 fps per nautical mile of redesignation even with thrust and altitude variations. With delta guidance, the cost of downrange  $\Delta$ RLS updates is less than the cost using explicit guidance provided the update is less than 35,000 ft. Crossrange  $\Delta$ RLS updates incur nearly identical  $\Delta V$  penalties with either delta or explicit guidance. The cost is a strong function of the time of the update and the update distance but the  $\Delta V$  cost is less than 30 fps if the update is no more than 18,000 ft. and is made within 6 minutes of descent ignition.

(NASA-CR-110469) DELTA RLS UPDATES DURING  
THE BRAKING PHASE OF LM DESCENT USING  
EXPLICIT AND DELTA GUIDANCE (Bellcomm, Inc.)  
13 p

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MEMORANDUM FOR FILE

In August, 1969, a study was made to evaluate the  $\Delta V$  cost of updating the landing site through the DSKY during the braking phase of the Apollo 11 LM descent trajectory [1]. Since that time, the trajectory parameters have been modified, resulting in a lower total  $\Delta V$  cost for the Apollo 12 and 13 trajectories [2]. This memorandum presents the results of updating the landing site during the braking phase using the new trajectory parameters. In addition, this study compares the effects of redesignating the site using the explicit guidance scheme versus using the delta guidance equations which control the trajectory by engine throttle pulses [3]. For both types of guidance,  $\pm 20,000$  ft. errors in altitude at ignition (PDI) and  $\pm 1\%$  thrust variations using the Apollo 12 engine model are considered.

The Bellcomm Powered Flight Performance Simulator was modified so that the landing site could be updated during the braking phase. The program simulates the LM powered descent, redesignating the site at a given time interval from 0 to 6 minutes after PDI. Crossrange redesignations were made up to 18,000 ft., and downrange redesignations were made up to 35,000 ft., in both positive (downrange) and negative (uprange) directions.

Table I contains data extracted from the simulations in which the explicit guidance scheme was used. Only negative crossrange updates are listed because these are symmetric with positive crossrange updates.\* The table indicates the time at which the site redesignation was made, the throttle-down time,\*\* switchover time (high gate), and the time of touchdown, given in seconds since PDI. The total  $\Delta V$  indicated is from PDI to touchdown in feet per second. It should be noted that redesignating the site closer causes a later throttle-down using the explicit guidance scheme, and thus gives less

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\*Crossrange  $\Delta$ RLS updates can be accomplished using the existing software but they are not anticipated due to lack of crossrange error information during descent.

\*\*The time between PDI and throttle recovery.

throttle control time during the braking phase. Throttle-control time varies from 44 sec. for a -35,000 ft. update to 164 sec. for a +35,000 ft. update in the downrange direction. The  $\Delta V$  cost of redesignating the site is approximately 8.5 ft. per sec. per nautical mile, e.g., the total  $\Delta V$  increased 50 ft. per sec. for a 35,000 ft. redesignation in the downrange direction. The time at which the update is entered into the DSKY has little effect on the cost of downrange updates up to 6 minutes after PDI. For crossrange updates, the  $\Delta V$  cost is insignificant for updates of up to 18,000 ft. if made within 4 minutes after PDI. However, at 6 minutes after PDI, the cost varies significantly with the distance.

Use of the delta guidance equations yields the data tabulated in Table II. The engine throttle pulses cause the  $\Delta V$  to vary incrementally with the number of pulses required to control the thrust, so the delta guidance data is not as smooth as that for explicit guidance. Within two minutes after PDI, the cost of redesignating the site in any direction is not significant for the distances indicated in the table. At 6 minutes after PDI (within 2 minutes of nominal throttle down), moving the site 35,000 ft. downrange causes an immediate pulse down which lasts for 38 sec. and incurs a  $\Delta V$  penalty of 33 fps. Moving the site 35,000 ft. closer at 6 minutes results in velocities so high that this guidance scheme cannot land the LM safely. It should be noted that  $\Delta RLS$  updates nominally occur 2 minutes after PDI and that a 35,000 ft. update is not expected. A comparison of downrange and crossrange results using explicit and delta guidance is shown in Figures 1 and 2.

Figure 3 (taken from Ref. 1) shows the  $\Delta V$  curves for downrange and crossrange redesignations made at 2 minutes after PDI, using the explicit guidance scheme with the Apollo 11 trajectory parameters. The slopes of these curves are nearly identical to those made with the Apollo 12, 13 trajectory parameters, but the total  $\Delta V$  for the new trajectory is approximately 140 ft. per sec. less than the total  $\Delta V$  for the Apollo 11 trajectory.

Errors in altitude at PDI and engine thrust variations were studied for effects on updating the site at 2 minutes after PDI. Both guidance schemes were used. Altitude errors of  $\pm 20,000$  ft. produced the results shown in Table 3 and in Figure 4. A redesignation costs approximately the same in  $\Delta V$  regardless of initial altitude errors; i.e., the slope of the  $\Delta V$  curve is not changed significantly by the altitude errors.

Table 4 and Figure 5 show the results of  $\pm 1\%$  variations in nominal engine thrust level. The nominal level is 93.81% of the maximum engine thrust of 10,500 lbs. When explicit guidance is used, redesignating closer costs less with a low thrust engine, and more with a high thrust engine. The engine thrust level makes less difference for positive downrange redesignations. When delta guidance is used, the thrust level makes little difference unless the thrust level is so low and the site is so close that throttle-down does not occur until later in the visibility phase. This is the same situation that develops at the nominal thrust level when the redesignations are made later than 4 minutes after PDI. The total  $\Delta V$  is less, but the trajectory may not be desirable in extreme cases because inadequate visibility time is available.

In conclusion, the effect of redesignating the landing site early in the braking phase of the Apollo 13 trajectory is similar to the effect seen on the Apollo 11 trajectory when the explicit guidance scheme is used. The cost of crossrange redesignations varies significantly with the time at which the update is entered into the DSKY. Downrange designation costs are mainly a function of the update distance. Altitude errors do not significantly change the effect of the redesignation with respect to the  $\Delta V$  cost. Variations in the engine thrust level do affect the trajectory when the site is redesignated a large distance uprange. When the delta guidance equations are used, the time at which the redesignation is made (if greater than 4 minutes past PDI) becomes significant for both crossrange and downrange updates of greater than 6000 ft.



P. A. Whitlock

2014-PAW-ksc

Attachments  
Tables I-IV  
Figures 1-5

**BELLCOMM. INC.**

REFERENCES

1. F. LaPiana and P. A. Whitlock, "ΔV Cost of Updating the Landing Site During the LM Descent Braking Phase", Case 310, Bellcomm Memorandum for File B69-08046, August 21, 1969.
2. P. A. Whitlock, "The Apollo 12 LM Descent Trajectory", Case 310, Bellcomm Memorandum for File B69-10078, October 24, 1969.
3. T. E. Moore, G. G. McSwain, J. D. Montgomery, "Guidance Laws for Controlling Off-Nominal LM Powered Descent Trajectories Back to the Nominal", MSC Internal Note EG-69-9, February 28, 1969.

TABLE I - EXPLICIT GUIDANCE  
APOLLO 12, 13 GUIDANCE TARGETS

SITE UPDATE	REDESIGNATION	TIME SINCE PDI	THROTTLE-DOWN	SWITCHOVER	TOUCHDOWN	TOTAL ΔV	ADDED COST
NOMINAL	0	388		502	676	6611	--
CROSSRANGE							
-6000.	0	388		502	676	6611	0
	120	388		502	676	6611	0
	240	388		502	676	6611	0
	360	388		502	676	6613	2
-10,000	360	390		502	676	6615	4
-12,000	0	388		502	676	6612	1
	120	388		502	676	6612	1
	240	388		502	676	6613	2
	360	390		504	678	6630	19
-15,000	240	390		502	676	6614	3
	360	390		504	678	6634	23
-18,000	0	388		502	676	6613	2
	120	388		502	676	6614	3
	240	390		502	676	6615	4
	360	392		504	678	6638	27
DOWNRANGE							
+35,000	0	362		526	700	6660	49
	120	362		524	698	6650	39
	240	362		524	698	6651	40
	360	368		526	700	6662	51
+18,000	0	374		514	688	6631	20
	120	374		514	688	6632	21
	240	374		514	688	6633	22
	360	376		516	690	6644	33
+12,000	0	378		510	684	6625	14
	120	378		510	684	6626	15
	240	378		510	684	6626	15
	360	380		510	684	6625	14
+6000.	0	384		506	680	6617	6
	120	384		506	680	6617	6
	240	384		506	680	6618	7
	360	384		506	680	6617	6
-6000.	0	394		498	672	6605	- 6
	120	394		498	672	6605	- 6
	240	394		498	672	6604	- 7
	360	394		498	672	6605	- 6
-12,000	0	400		494	668	6601	- 10
	120	400		494	668	6600	- 11
	240	400		494	668	6600	- 11
	360	398		494	668	6603	- 8
-18,000	0	406		488	662	6586	- 25
	120	406		488	662	6584	- 27
	240	406		488	662	6583	- 28
	360	404		488	662	6589	- 22
-35,000	0	428		472	646	6561	- 50
	120	426		472	646	6557	- 54
	240	426		472	646	6555	- 56
	360	424		472	646	6570	- 41

TABLE II - DELTA GUIDANCE

SITE UPDATE	REDESIGNATION	TIME SINCE PDI	THROTTLE-DOWN	SWITCHOVER	TOUCHDOWN	TOTAL $\Delta V$	ADDED COST
NOMINAL	0	470	468	642	6519	--	--
CROSS RANGE							
-6000.	0	470	468	642	6516	- 3	
	120	470	468	642	6516	- 3	
	240	470	468	642	6517	- 2	
	360	470	468	640	6511	- 8	
-12,000	0	470	468	642	6517	- 2	
	120	470	468	642	6517	- 2	
	240	470	468	642	6519	0	
	360	470	468	642	6533	14	
-18,000	0	470	468	642	6518	- 1	
	120	470	468	640	6511	- 8	
	240	472	468	642	6524	5	
	360	470	468	640	6540	21	
DOWN RANGE							
+35,000	0	478	476	648	6523	4	
	120	478	476	650	6524	5	
	240	482	480	652	6527	8	
	360	490	488	662	6552	33	
+18,000	0	474	472	646	6523	4	
	120	474	472	646	6521	2	
	240	476	474	646	6516	- 3	
	360	480	478	650	6519	0	
+12,000	0	472	470	644	6515	- 4	
	120	474	472	646	6530	11	
	240	474	472	646	6524	5	
	360	478	476	648	6528	9	
+6000.	0	472	470	642	6514	- 5	
	120	472	470	644	6524	5	
	240	472	470	644	6521	2	
	360	474	472	646	6528	9	
-6000.	0	470	468	640	6515	- 4	
	120	470	468	640	6515	- 4	
	240	470	468	642	6532	13	
	360	470	466	638	6516	- 3	
-12,000	0	468	466	638	6511	- 8	
	120	468	466	638	6512	- 7	
	240	468	466	640	6530	11	
	360	472*	454	622	6447	- 72	
-18,000	0	468	466	640	6531	12	
	120	466	464	638	6518	- 1	
	240	464	462	636	6519	0	
	360	482*	446	598	6352	-167	
-35,000	0	464	460	634	6512	- 7	
	120	460	458	632	6509	- 10	
	240	484*	438	578	6274	-245	
	360	---	428		crash		

\*Throttle down late

TABLE III - EFFECTS OF ALTITUDE ERRORS

ALT @ PDI	SITE UPDATE	REDESIGNATION	TIME SINCE PDI	THROTTLE-DOWN	SWITCHOVER	TOUCHDOWN	TOTAL ΔV	ADDED COST
<b>A. EXPLICIT GUIDANCE (APOLLO 12, 13 GUIDANCE TARGETS)</b>								
30,000	0	0	396	496	670	6585	-26	
70,000	0	0	386	506	680	6644	33	
DOWNRANGE								
30,000	35,000	120	358	520	694	6630	19	
30,000	18,000	120	380	508	682	6603	- 8	
30,000	-18,000	120	414	480	654	6553	-58	
30,000	-35,000	120	440	460	634	6514	-97	
70,000	35,000	120	360	528	702	6686	75	
70,000	18,000	120	372	518	692	6667	56	
70,000	-18,000	120	402	494	668	6627	16	
70,000	-35,000	120	422	478	652	6594	-17	
CROSSRANGE								
30,000	-18,000	120	396	496	670	6588	-23	
70,000	-18,000	120	386	506	680	6646	35	
<b>B. DELTA GUIDANCE</b>								
30,000	0	0	470	468	640	6506	-13	
70,000	0	0	472	470	642	6541	22	
DOWNRANGE								
30,000	35,000	120	480	476	648	6511	- 8	
30,000	18,000	120	474	472	644	6508	-11	
30,000	-18,000	120	466	464	638	6522	3	
30,000	-35,000	120	460	456	630	6498	-13	
70,000	35,000	120	480	478	650	6549	30	
70,000	18,000	120	476	474	646	6546	27	
70,000	-18,000	120	468	466	638	6543	24	
70,000	-35,000	120	462	460	632	6538	19	
CROSSRANGE								
30,000	-18,000	120	472	468	640	6510	- 9	
70,000	-18,000	120	472	470	642	6544	25	

TABLE IV - EFFECTS OF ENGINE THRUST VARIATIONS

THRUST LEVEL	SITE UPDATE	REDESIGNATION	TIME SINCE PDI	THROTTLE-DOWN	SWITCHOVER	TOUCHDOWN	TOTAL AV	ADDED COST
<b>A. EXPLICIT GUIDANCE</b>								
-19%	0	0		406	496	670	6597	- 14
+19%	0	0		374	508	682	6629	18
<b>DOWNRANGE</b>								
-1%	35,000	120		374	520	694	6641	30
-1%	18,000	120		388	510	684	6627	16
-1%	-18,000	120		426	480	654	6570	- 41
-1%	-35,000	120		456	456	630	6522	- 89
+1%	35,000	120		350	528	702	6662	51
+1%	18,000	120		360	518	692	6643	32
+1%	-18,000	120		288	496	670	6609	- 2
+1%	-35,000	120		406	482	656	6582	- 29
<b>CROSSRANGE</b>								
-1%	-18,000	120		406	496	670	6600	- 11
+1%	-18,000	120		374	508	682	6631	20
<b>B. DELTA GUIDANCE</b>								
-1%	0	0		470	468	642	6519	0
+1%	0	0		472	468	642	6514	- 5
<b>DOWNRANGE</b>								
-1%	35,000	120		480	476	648	6512	- 7
-1%	18,000	120		476	472	644	6510	- 9
-1%	-18,000	120		466	464	638	6523	4
-1%	-35,000	120		470	446	608	6402	-117
+1%	35,000	120		478	476	650	6524	5
+1%	18,000	120		476	474	646	6523	4
+1%	-18,000	120		468	464	638	6513	- 6
+1%	-35,000	120		462	460	632	6508	- 11
<b>CROSSRANGE</b>								
-1%	-18,000	120	470*		468	642	6521	2
+1%	-18,000	120	472		470	642	6524	5

\*Throttle down late

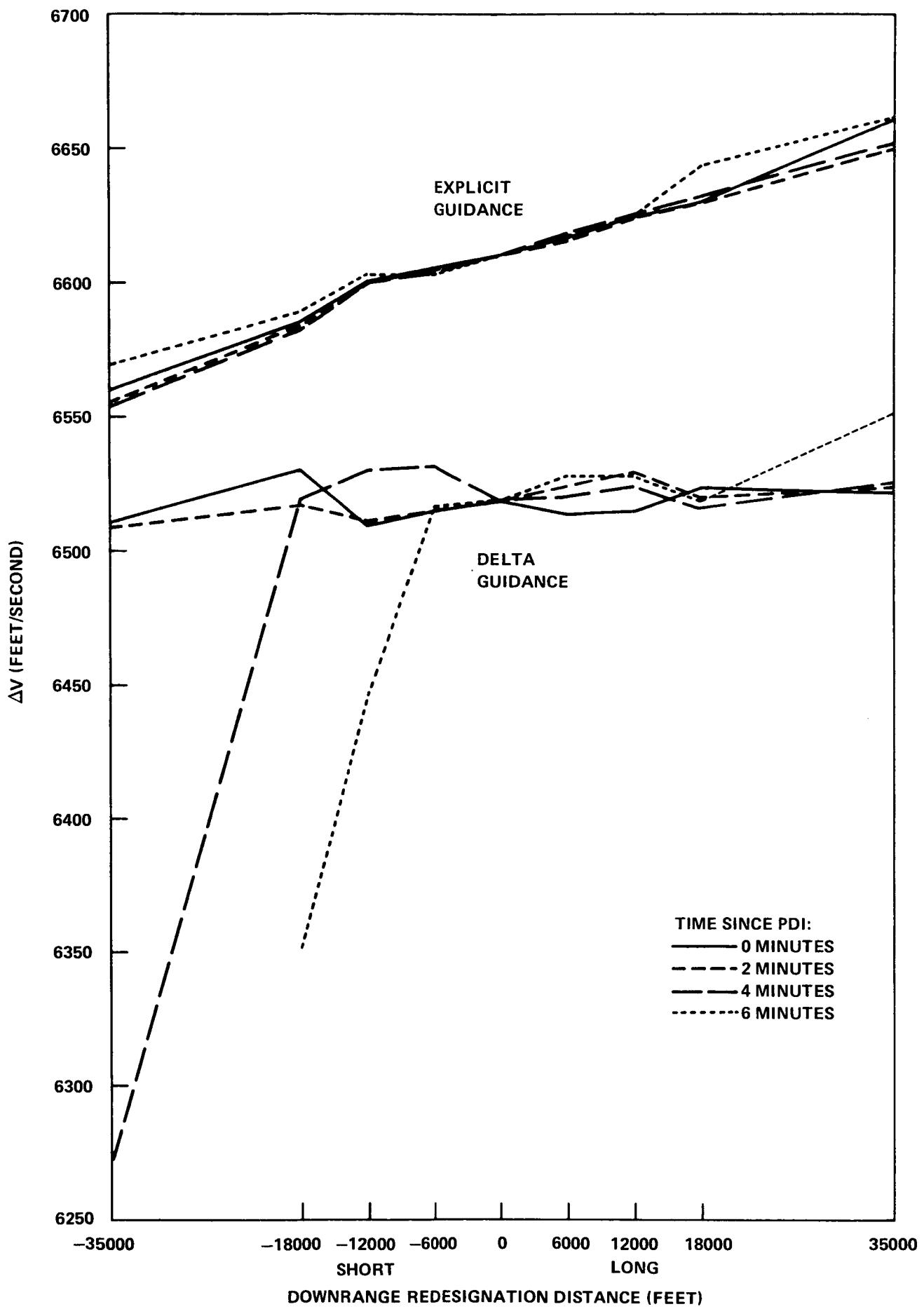


FIGURE 1 - DOWNRANGE REDESIGNATIONS WITH EXPLICIT AND DELTA GUIDANCE

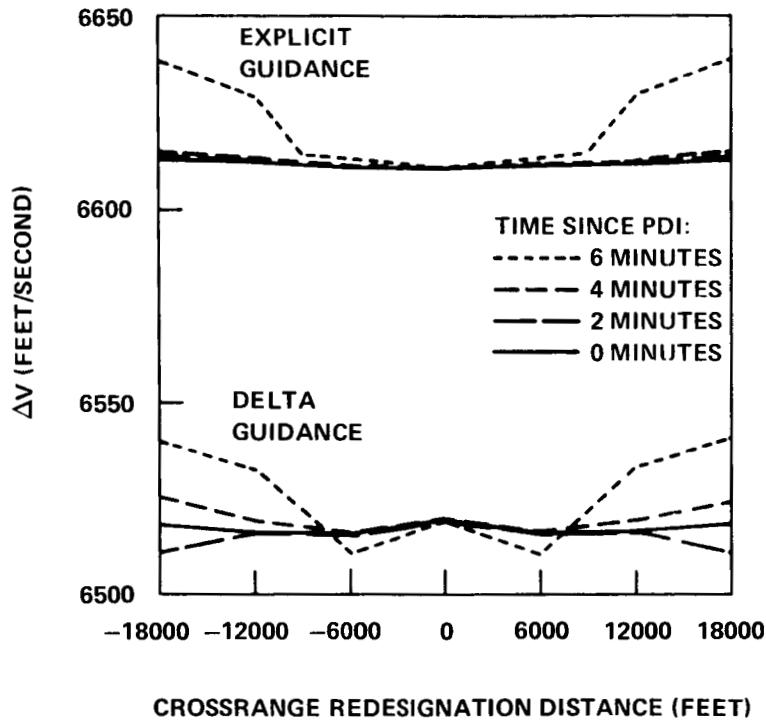
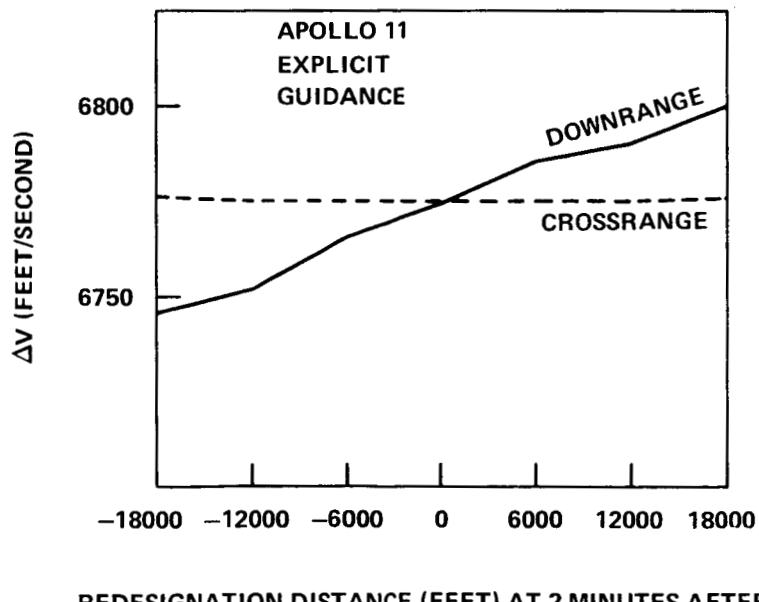


FIGURE 2 - CROSSRANGE REDESIGNATION WITH EXPLICIT AND DELTA GUIDANCE



REDESIGNATION DISTANCE (FEET) AT 2 MINUTES AFTER PDI

FIGURE 3 - APOLLO 11 REDESIGNATIONS

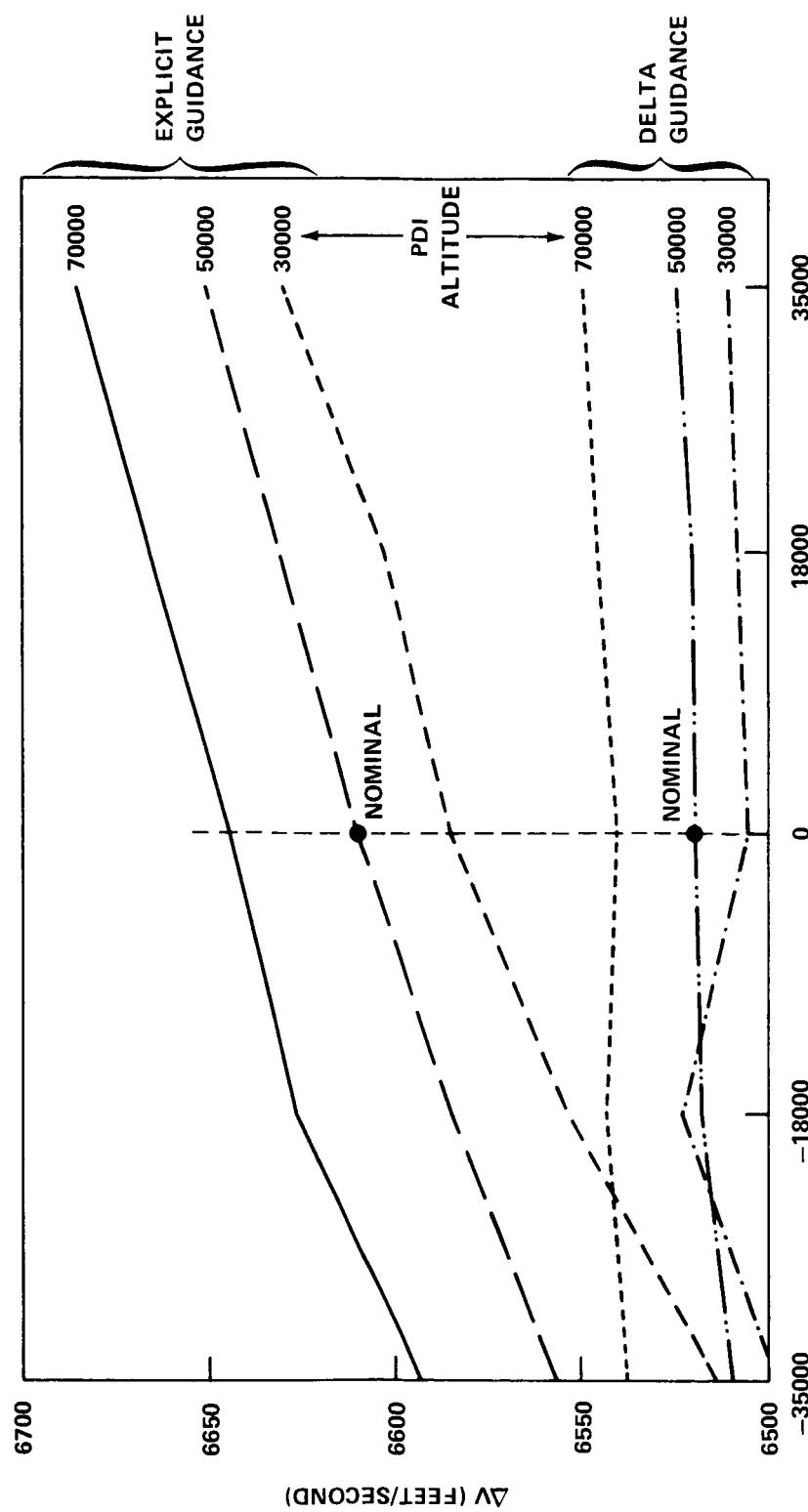


FIGURE 4. EFFECTS OF ALTITUDE ERRORS

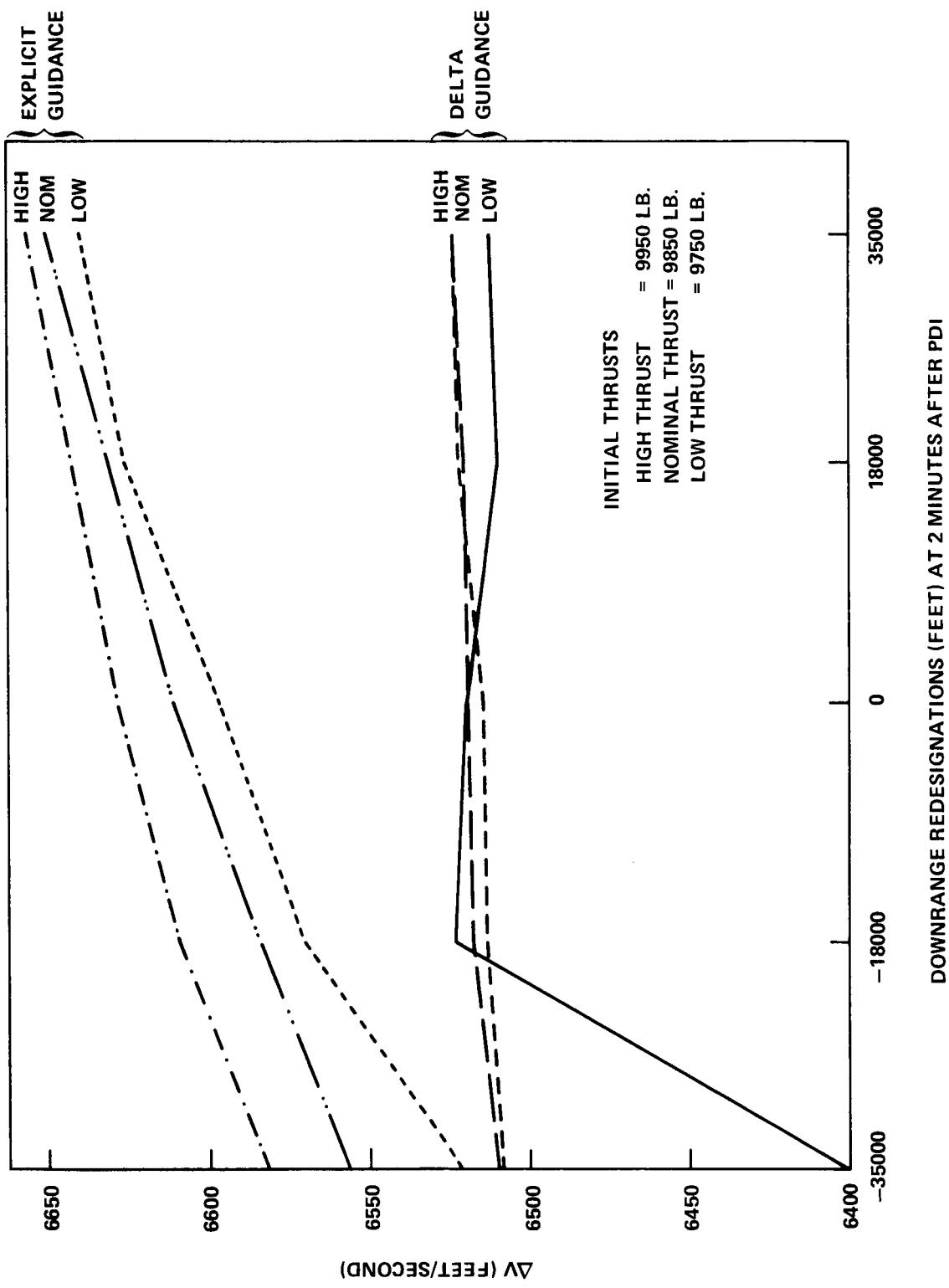


FIGURE 5. EFFECTS OF ENGINE THRUST VARIATIONS

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